THE EFFECT OF BORAX ON THE YIELD, QUALITY, AND CHEMICAL COMPOSITION OF CANNING BEETS

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THE EFFECT OF BORAX ON THE YIELD, QUALITY, AND CHEMICAL COMPOSITION OF CANNING BEETS.

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INTRODUCTION

The progressive development in knowledge of the relation of boron to growing plants has been promoted by the studies of many investigators. The principal contributions to the present knowledge of this subject have been made since the beginning of the present century. Through careful experiments it has been shown that an adequate supply of available boron is essential for normal growth of many species of plants. When the supply of boron available to a plant is inadequate, there occur physiological disturbances which, in turn, are usually reflected in the appearance of the plant. When symptoms of boron starvation were recognized in the appearance and yield of economic plants growing on certain soils, a new problem appeared within the realm of the soil scientist.

REVIEW OF LITERATURE

The Role of Boron in Plants

The status of boron as an essential plant nutrient has been established by the studies of Warington (3, 21, 22), Brenchley (2,3), Dennis (6,8), Dennis and O'Brien (7), and others.

The exact role played by this element in the life and growth of plants is apparently unknown. However, many fragmentary bits of evidence regarding the effects of faulty boron nutrition have come from workers who have studied the problem.

White-Stevens (23), in an attempt to correlate and unify the important discoveries and observations of others, has presented an excellent summary of the relation of improper boron nutrition to external plant symptoms and to internal physiology:

(a) Relation to external symptoms.

(1) Inadequate boron nutrition inhibits meristematic activity and often causes death and decay of the apical meristem, lateral buds, cambium layers, and root tip.

(2) The functional activity of the vascular tissue is impaired as the phloem becomes disorganized and hypertrophied.

(3) Foliage degeneration, due to disorganized meristematic activity, appears first in the younger leaves. Older leaves may later show necrosis, excess anthocyanin formation, and a distinct turgidity and leatherness which results in brittleness.

(4) The roots, on account of death of the tips, branch excessively and cease active growth. Storage roots and tubers fail to enlarge normally but develop center rot or surface lesions which become infected with secondary organisms.

(5) Fruits and fruiting tissues follow a similar degeneration, cessation of growth, internal and peripheral decay.

(b) Relation to internal physiology.

The disturbances in a particular part of a plant cannot be ascribed solely to lack of boron in the affected region. There is evidence of fairly even distribution of boron throughout the plant. When the supply entering a plant is limited, the boron of old leaves is not translocated to the growing tips.

The available evidence seems to indicate that a disruption in the food-conducting cells of the vascular tissue is the initial physiological disorder.

This disruption of phloem activities causes interruptions both in the movement of nutrients from the soil to the upper plant parts, and in carbohydrate transfer from the regions of synthesis.

Canning Beet Studies

Commercial canners have for several years been troubled by a condition in beets, known in various localities as canker, girdle, internal or physiological breakdown, and internal black spot. Due to its presence, canning operations have been retarded and canners have not only been obliged to use additional inspectors, but they have also faced the hazard of defective beets escaping detection and appearing in the final pack. Losses to growers are of two forms: dockage losses and low acre yields.

In 1937, Raleigh and Raymond (15) issued a preliminary report on their attempt to control internal breakdown of table beets by the use of boron. A greenhouse experiment was conducted, using a soil from a field in which the beets were affected the previous year. Boron, applied as borax, greatly reduced both the severity of the disorder and the percentage of beets affected, while the salts of several other secondary fertilizer components had no great effect. In a field experiment, an application of 5 pounds of borax in a trench at the side of the row gave nearly complete control.

A report (11) from the New York Experiment Station (Geneva) states that in greenhouse tests physiological breakdown was greatly reduced by an application of 12 pounds of borax or 12 tons of manure per acre.

Walker and coworkers (20) of Wisconsin have described internal black spot and the characteristic features which accompany it. They found no parasitic fungus or bacterium in the internal black spot tissue. In field experiments, borax and other salts were applied, both broadcast and in bands on each side of the row. The borax treatments reduced both the percentage of affected beets and the severity of the blackening, and resulted in small increases in yield. An application of 40 pounds of borax per acre was recommended.

Other papers by Walker (17, 18, 19), based on later studies, report greater yield increases and an improvement in stand resulting from borax applications.

Powers and Bouquet (13) have cited the incidence of canker in Oregon. In greenhouse and field experiments the condition was virtually eliminated by applications of either boric acid or borax. Other substances failed to control the canker.

White-Stevens found the sugar content of roots of normal red beets higher than that of beets receiving an inadequate supply of boron. The leaves of normal beets contained less sugar than those of the affected beets.

Raleigh and coworkers (14) have reported the results of a continuation of earlier studies. Control of internal breakdown by the use of borax was more satisfactory on low-yielding fields than on high-yielding ones. An application of 500 pounds of sulfur per acre had no noticeable effect on the breakdown. In studies of affected beets, the first appearance of the breakdown of the root was found in the meristematic parenchyma tissue adjacent to the xylem.

Cook and Millar (5) have reported greenhouse and field experiments with borax for canning beets. In a greenhouse experiment, symptoms of boron starvation were completely eliminated and yields were greatly increased by applying borax at the rate of 10 pounds per acre. In field experiments on three different farms in 1939, borax, drilled deeply before planting, decreased the percentage of abnormal beets, but there was no effect on the yield. The quantity of borax required to reduce significantly the percentage of abnormal beets varied from 10 pounds to 30 pounds per acre on the different fields. This variation was ascribed to differences in soil texture and organic matter content.

In field experiments conducted by Cook (4) during the season of 1940, black spot was more serious in beets which had received 250 pounds of 2-12-6 fertilizer. It is believed that this was due to the inadequacy of the available boron supply for the increased yield of beets. The addition of borax to the fertilizer and its application, either broadcast or in the row, resulted in a higher percentage of sound beets. In no case, however, did a great increase in yield result from a borax application. Broadcast applications up to 80 pounds per acre did not depress the yield, but on certain soils row applications of 30 pounds per acre greatly reduced the yield.

EXPERIMENTAL

Field Procedure

Canning beets were included in a field experiment, conducted in 1940, to determine the effect of borax on a number of field and garden crops.

The experiment was located on an area of Thomas sandy loam on which signs of severe boron starvation were observed in sugar beets in 1939. The soil in this field contains free carbonates in the plowed layer and the organic matter content ranges from 14 to 18 per cent. At a depth of 12 inches, there is a 10-inch sandy layer overlying heavy clay.

Borax was applied in a basic fertilizer mixture at rates of 0, 10, 20, 40, and 80 pounds per acre. The basic mixture included the following materials at the rates per acre indicated: 3-12-12, 500 pounds; NaI, 0.5 pounds; $ZnSO_4$, 4 pounds; $MgSO_4$, 25 pounds; $MnSO_4$, 25 pounds; $FeSO_4$, 2 pounds; NaCl, 10 pounds; and $CuSO_4$, 5 pounds. One treatment included only the 3-12-12 fertilizer. All treatments were replicated five times and were arranged in randomized blocks. The fertilizers were drilled and worked into the soil immediately before planting. The beets were planted May 8 and were harvested October 13.

Methods of Analysis

Plant tissue dried at 65° C and ground to pass a 1-mm. sieve was used in the analyses reported in this paper.

Boron was determined by the quinalizarin method of Berger and Truog (1).

Total nitrogen was determined by a modified Gunning method.

Iron was determined by titrating the ferric ion with standard titanium chloride.

Ash was determined by ignition in a muffle furnace to a light gray ash.

Sucrose was measured in the juice of the beets by means of a saccharimeter*.

*The writer acknowledges the courtesy of J. G. Lill in making the sucrose determinations.

Results

The data which appear in Table 1 are the results of the field experiment and of the chemical analyses included in this study.

Yield

The application of borax in this experiment resulted in highly significant increases in the yield of beets. The yield with the application of 80 pounds of borax was 91 per cent greater than the average yield of the two treatments without borax.

Since the greater rates of borax application caused no decrease in yield, it may reasonably be concluded that the application of borax at rates up to 80 pounds per acre was not injurious to canning beets on this soil. In fact, it seems possible that a greater increase in yield might have resulted from a still heavier application of borax.

Symptoms of Boron Starvation

It became apparent as the season progressed that the beets in the areas not treated with borax were not receiving adequate boron.

One indication was the more intense red coloration of the leaves of these plants. This condition was not easily detected from observations of single plants, but there was a noticeable difference in redness when beets in borax-treated areas were compared from a distance with those in areas not treated with borax.

Certain other leaf symptoms also gave evidence of boron starvation. One of these symptoms was the stimulated initiation of leaves at the center of the crown. These leaves failed to attain normal size and shape, and were dwarfed, twisted, and non-symetrical. The upper surfaces of the petioles were frequently cracked and cross-checked. These symptoms are apparent in Figure 1, which shows a plant in pot culture.

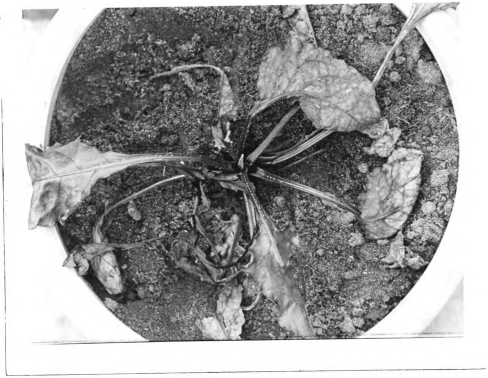

Figure 1. This plant, growing in pot culture, shows twisted, non-symetrical leaves with cross-checked petioles, which are symptoms of boron starvation.

At the time of harvest, marked differences were found in the quality of the beets. Cankers were common on the roots of those which had not received adequate boron. In extreme cases, cankers, at or slightly below the soil line, had completely encircled the roots, and a girdled condition had resulted. The beets shown in Figure 2 are not completely girdled, but external cankers are plainly visible.

Figure 2. These beets are not completely girdled, but external cankers are plainly visible.

When the girdled roots were sliced horizontally, the dark necrotic areas were found principally confined to an irregular but usually quite narrow zone near the periphery. The affected zones are prominent in the sliced beets on the right in Figure 3. Isolated necrotic areas sometimes occurred in the internal regions, but such instances were uncommon.

Figure 3. Girdled roots show dark, necrotic areas, which are usually confined to a narrow zone near the periphery.

The percentage of beets showing partial or complete girdling was determined for each treatment. As shown in Table 1, girdling affected an average of nearly 57 per cent of the beets in the areas which had not received borax. The percentage of affected beets in the areas which had received 10 pounds of borax per acre was not significantly lower than that of the beets in the areas not treated with borax. The percentage was significantly reduced in areas which had received 20, 40, and 80 pounds of borax per acre. Girdling was not completely eliminated, although it was not found in two replicates of the 80-pound borax treatment.

Chemical Composition

Sucrose. The sucrose content of beets from the borax-treated areas was higher than that of the beets from areas not treated with borax. Although there was a difference in this respect for all rates of borax application, only those differences from the 20 and 80-pound rates were great enough to be significant. The 20-pound rate of application was most effective in increasing the sucrose content of the beets.

Purity. The coefficient of apparent purity is a figure expressing the ratio between the amount of sucrose in solution in the juice and the total soluble substances in the juice. The effect of borax on the purity of the beets was similar to its effect on the sucrose content. Since purity expresses a proportion, it is obvious that its value will change when either of its components changes. The data were examined to determine whether the increase in purity was partly due to a decrease in the total soluble substances in the juice. These substances, other than sucrose, probably are mainly nitrogenous compounds. It was found that the total amount of soluble substances remained nearly constant. Therefore, the increase in purity which resulted from borax applications was due entirely to a corresponding increase in sucrose content.

Nitrogen. The average nitrogen content of the beet tops from areas without borax was slightly higher than that of tops from borax-treated areas. This difference, however, is not large enough to be significant. The nitrogen content of the roots shows a greater decrease as a result of borax applications. The amount of this decrease is reasonably consistent with the amount of borax applied. Several of the differences in nitrogen content of the roots are highly significant.

Boron. The sample of beet tops from one of the control replicates contained 21 p.p.m. of boron. This caused the mean boron content for this treatment to be unreasonably high. The increase in boron content of the tops clearly reflects the borax treatments. Although there is no difference in this respect between the 20 and 40-pound rates, the other differences are consistent with the rates of application. The boron content of the roots did not differ significantly, but roots from areas which had received borax at the maximum rate had the highest boron content.

Iron. No significant differences occurred in the iron content of the beet tops. Borax treatments did, however, result in lower iron contents of the roots. The greater rates of application did not further decrease the iron content.

Ash. The mean ash content of the samples of beet tops from the areas receiving 20 pounds of borax per acre was 18.39 per cent. This value, according to the difference required for significance, might appear to be significantly lower than those of certain other treatments. However, the low "F" value indicates that this difference cannot be regarded as significant. Borax treatments significantly reduced the ash content of the roots. The differences are highly significant for the treatments with and without borax, but further decreases in ash content did not result from greater rates of borax application.

DISCUSSION

The root symptoms observed in this experiment apparently were identical with those described by Raleigh and Raymond, and Powers and Bouquet. As previously stated, the affected areas were generally confined to a narrow zone near the periphery of the root, and the presence of surface cankers gave rise to a girdled condition. In contrast, the symptom described by Walker and coworkers was predominantly an internal blackening of the root. The latter type of symptom has also been reported by Cook and Millar.

There is no apparent explanation for the occurrence of the two fairly distinct types of symptoms. It has been proven conclusively, however, that both indicate an inadequate supply of available soil boron. Furthermore, the results of this experiment, together with the credible evidence contributed by previous investigators, show that these symptoms can be virtually eliminated by the application of borax. It is clear that the amount of borax necessary to reduce the disorder to a minimum varies with the particular soil under treatment. Due to the injurious effects of an excessive amount of borax, it is obviously essential to limit the rate of application.

The results of other field experiments have shown occasional instances of moderate increases in the yield of beets from borax applications. The order of the increase obtained in this experiment, however, indicates that borax applications to certain soils may result in a great improvement in the yield of beets.

High sucrose content is probably an important factor in the palatability of canning beets. It is evident from the data that the roots of beets receiving inadequate boron contain less sucrose than those of normal beets. Analyses reported by White-Stevens have shown this to be true.

White-Stevens also reported that in the case of an inadequate supply of available boron the leaves of beets contain more than the normal amount of sugar. Although the sugar content of the leaves was not determined in this study, it seems possible that the greater red coloration observed in the leaves of plants in areas not treated with borax may be an indication that these leaves contained a relatively large amount of sugar. The red pigmentation of beet leaves is due to the presence of anthocyanin pigments. Many workers (12,16), in studies of other plants, have found that the amount of anthocyanin depends primarily upon the amount of sugar present. Thus it appears that an accumulation of sugar in the beet leaves was probably the principal factor in the formation of excess anthocyanin. Furthermore, the presence of excess sugar in the leaves may be explained as due to a disruption in the process by which sugar is normally transferred to the root for storage. Haas and Klotz (10) found that boron starvation in Citrus causes an impairment of the functional activity of the vascular tissue, which results in an accumulation of sugars in the leaves.

The abnormally high nitrogen content found in the roots of beets receiving inadequate boron is in agreement with data reported by several investigators. The reports show many instances of unusually high nitrogen contents of both leaves and roots of such plants. Two suggestions have been offered as possible explanations. The high nitrogen content may be due either to retarded plant growth, or to the inadequacy of the boron supply, which, according to this theory, normally functions to regulate the intake of nitrogen.

It is evident from the data that the boron content of plants showing symptoms attributed to boron starvation is less than that of normal plants. It is important to note in this connection that, as the incidence of symptoms was reduced by borax treatments, the boron content of the leaves increased markedly, but the content of this element in the roots did not increase significantly. This seems to prove that the defects which occur in the roots are not caused simply by lack of boron in the affected tissue.

The abnormally high iron and total ash contents of plants receiving inadequate boron has been reported by several investigators. As in the case of the high nitrogen content, these may be due either to retarded plant growth or to the effect of boron on the intake of iron and other ash elements.

SUMMARY

Canning beets were grown on an area of Thomas sandy loam in which sugar beets the previous year had shown symptoms of boron starvation. One treatment included only an application of 3-12-12 fertilizer. Another treatment consisted of an application of 3-12-12 fertilizer, together with a mixture of secondary fertilizer components other than boron. Other treatments included the 3-12-12 fertilizer and a mixture of secondary fertilizer components with borax supplied at the rates of 10, 20, 40, and 80 pounds per acre.

It was found that beets growing in the areas not receiving borax showed root symptoms of boron starvation which differed from the characteristic internal black spots described by other workers. The root symptom observed in this experiment was predominantly a girdled condition of the surface due to the presence of relatively shallow cankers.

These symptoms were virtually eliminated by the application of borax at the rate of 80 pounds per acre. Further improvements in the quality of the roots resulted from increased purity and sucrose content of the beets.

Borax treatments resulted in a marked improvement in the yield of beets.

As the result of borax applications, the boron content of the leaves increased very significantly, but the boron content of the roots did not increase significantly.

Boron starvation was accompanied by unusually high nitrogen, iron, and total ash contents of the root tissue.

The effect of borax on the yield, quality, and chemical composition of canning beets.

reatment	Rate of Borax -(pounds per acre)	Yield (tons)	% Girdling	Chemical composition[2]									
				% Sucrose	Purity	% Nitrogen		Boron - p.p.m.		% Fe_2O_3		% Ash	
						Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots
ontrol[1]	0	7.54	58.7	3.21	45.4	3.97	3.19	13.2	11.0	.4301	.1446	19.41	17.10
o borax	0	6.74	57.2	3.21	43.9	3.86	3.28	8.6	11.4	.3954	.1737	19.88	16.17
orax	10	11.14	46.3	3.52	47.4	3.77	2.74	16.0	11.8	.4549	.1251	19.02	14.90
orax	20	10.74	13.7	4.28	55.1	3.78	2.60	20.8	11.4	.4104	.1031	18.39	13.07
orax	40	11.38	10.5	3.55	47.7	3.86	2.61	20.2	12.0	.4558	.1189	19.62	14.40
orax	80	13.68	4.3	4.08	52.6	3.79	2.33	26.6	13.2	.4486	.1090	18.85	13.46
value		5.73**	35.3**	2.84*	6.09**	.68	26.5**	31.27**	.60	.70	5.41**	1.21	8.92**
(5% point)		2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71
(1% point)		4.10	4.10	4.10	4.10	4.10	4.10	4.10	4.10	4.10	4.10	4.10	4.10
ifference required for significance		3.17	12.3	.75	5.17	.27	.21	3.36	2.93	.090	.033	1.47	1.88

This treatment included only an application of 500 pounds of 3-12-12 fertilizer. The materials applied in all other treatments were uniform except for borax, and included the following materials at the rates per acre indicated: 3-12-12, 500 lbs,; NaI, 0.5 lbs.; $ZnSO_4$, 4 lbs.; $MgSO_4$, 25 lbs.; $MnSO_4$, 25 lbs.; $FeSO_4$, 2 lbs.; NaCl, 10 lbs.; and $CuSO_4$, 5 lbs. All treatments were replicated five times.

The nitrogen, boron, iron, and ash contents were determined on tissue dried at 65° C. In taking the samples for these four determinations from the areas not receiving borax, an attempt was made to select beets showing girdling.

*Significant to 5% point.

*Significant to 1% point.

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